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1. REPORT DATE *(DD-MM-YYYY)* 13-08-2009	2. REPORT TYPE Conference Proceeding		3. DATES COVERED *(From - To)*
4. TITLE AND SUBTITLE Combining Satellite Ocean Color Imagery and Circulation Modeling to Forecast Bio-Optical Properties: Comparison of Models and Advection Schemes		**5a. CONTRACT NUMBER**	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER 060153N	
6. AUTHOR(S) Richard W. Gould, Rebecca E. Green, Tamara L. Townsend, Dong Shan Ko, Regina Smith, Peter M. Flynn, Brandon Casey, Robert A. Arnone		**5d. PROJECT NUMBER**	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER 73-9435-08-5	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory Oceanography Division Stennis Space Center, MS 39529-5004	8. PERFORMING ORGANIZATION REPORT NUMBER NRL/PP/7330-08-8277
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research 800 N. Quincy St. Arlington, VA 22217-5660	10. SPONSOR/MONITOR'S ACRONYM(S) ONR
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution is unlin

20090821537

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Remote sensing of ocean color provides synoptic surface ocean bio-optical properties but is limited to real-time or climatological applications. Many applications, including navy mission planning using electro-optical sensor performance models, would benefit from a forecast capability. To achieve this, we couple satellite imagery with numerical circulation models to provide short-term (24-48 hr) forecasts of bio-optical properties at 1km and 250m resolution. These are first-order approaches; they do not account for any biogeochemical mechanistic processes (growth, grazing, sinking, resuspension), only dynamical processes (currents). Nonetheless, by comparing forecast distributions with next-day satellite imagery, we can assess errors and estimate how strongly the physical processes control the bio-optical distribution patterns. We compare three Navy models and two advection approaches. The Hybrid Coordinate Ocean Model (HYCOM), the Navy Coastal Ocean Model (NCOM), and the Advanced Circulation Model (ADCIRC) provide current direction and magnitude at hourly time-steps, at 4km, 2km, and up to 50m resolution, respectively. We apply the current vectors from these models to the satellite-derived (SeaWiFS, MODIS) bio-optical properties (chlorophyll, backscattering coefficient, and total suspended matter concentration) to produce advected, forecast images, using both a tracer advection scheme (Eulerian approach) and a particle trajectory/accumulation scheme (Lagrangian approach). Difference images between the next-day, satellite-derived optical fields and the model-advected fields provide a quantitative assessment of the forecast accuracy of the three models and two advection schemes.

15. SUBJECT TERMS

HYCOM, remote sensing, bio-optical properties, imagery

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Richard Gould
a. REPORT	b. ABSTRACT	c. THIS PAGE	UL	14	
Unclassified	Unclassified	Unclassified			19b. TELEPHONE NUMBER *(Include area code)* 228-688-5587

PUBLICATION OR PRESENTATION RELEASE REQUEST

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1. REFERENCES AND ENCLOSURES	2. TYPE OF PUBLICATION OR PRESENTATION		3. ADMINISTRATIVE INFORMATION
Ref: (a) NRL Instruction 5600.2 (b) NRL Instruction 5510.40D Encl: (1) Two copies of subject paper (or abstract)	( ) Abstract only, published ( ) Book ( ) Conference Proceedings (refereed) ( ) Invited speaker ( ) Journal article (refereed) ( ) Oral Presentation, published ( ) Other, explain	( ) Abstract only, not published ( ) Book chapter (X) Conference Proceedings (not refereed) ( ) Multimedia report ( ) Journal article (not refereed) ( ) Oral Presentation, not published	STRN NRL/PP/7330-08-8277 Route Sheet No. 7330/ Job Order No. 73-9435-08-5 Classification X U C Sponsor ONR approval obtained ____ yes X no

4. AUTHOR

Title of Paper or Presentation

Combining Satellite Ocean Color Imagery & Circulation Modeling to Forecast Bio- Optical Properties: Comparison of Models & Advection Schemes

Author(s) Name(s) (First,MI,Last), Code, Affiliation if not NRL

Richard W. Gould, Rebecca E. Green, Tamara L. Townsend, Dong Shan Ko, Regina Smith, Peter M. Flynn, Brandon Casey, Robert A Arnone

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(Name of Conference)

06- OCT - 10- OCT- 08, Tuscany, Italy, Unclassified
(Date, Place and Classification of Conference)

and/or for publication in   **Ocean Optics XIX Conference, Unclassified**
(Name and Classification of Publication)   *(Name of Publisher)*

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5. ROUTING/APPROVAL

CODE	SIGNATURE	DATE	COMMENTS
Author(s) Gould	R W Gould	9/5/08	Need by 22 Sept 08
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Section Head N/A			
Branch Head Robert A Arnone, 7330			
Division Head Ruth H. Preller, 7300	Ruth Bun	9/5/08	1. Release of this paper is approved. 2. To the best knowledge of this Division, the subject matter of this paper (has ____) (has never _X_) been classified.
Security, Code 1226			1. Paper or abstract was released. 2. A copy is filed in this office. 550 325
Office of Counsel,Code 1008.3	Sellenfor A Bude	9/12/08	
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Author(s) Gould	RW Gould	9/5/08	Need by 22 Sept 08
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Section Head N/A			
Branch Head Robert A Arnone, 7330	Arnone	9/5/08	
Division Head Ruth H. Preller, 7300	Ruth H. Preller	9/5/08	1. Release of this paper is approved. 2. To the best knowledge of this Division, the subject matter of this paper (has ___) (has never X) been classified.
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Combining Satellite Ocean Color Imagery and Circulation Modeling to Forecast Bio-Optical Properties: Comparison of Models and Advection Schemes

Gould, R.W., Jr.[1], R.E. Green[1], T.L. Townsend[2], D.S. Ko[3], R. D. Smith[4], P.M. Flynn[5], B.J. Casey[6], R.A. Arnone[7]

[1]Code 7333, Naval Research Laboratory, Stennis Space Center, MS, USA 39529
[2]Code 7323, Naval Research Laboratory, Stennis Space Center, MS, USA 39529
[3]Code 7322, Naval Research Laboratory, Stennis Space Center, MS, USA 39529
[4]OTI, Naval research Laboratory, Stennis Space Center, MS, USA 39529
[5]Code 7334, Naval Research Laboratory, Stennis Space Center, MS, USA 39529
[6]Planning Systems, Inc., Naval Research Laboratory, Stennis Space Center, MS, USA 39529
[7]Code 7330, Naval Research Laboratory, Stennis Space Center, MS, USA 39529

ABSTRACT

Remote sensing of ocean color provides synoptic surface ocean bio-optical properties but is limited to real-time or climatological applications. Many applications, including navy mission planning using electro-optical sensor performance models, would benefit from a forecast capability. To achieve this, we couple satellite imagery with numerical circulation models to provide short-term (24-48 hr) forecasts of bio-optical properties. These are first-order approaches; they do not account for any biogeochemical mechanistic processes (growth, grazing, sinking, resuspension), only dynamical processes (currents). Nonetheless, by comparing forecast distributions with next-day satellite imagery, we can assess errors and estimate how strongly the physical processes control the bio-optical distribution patterns.

We compare optical forecast results from three Navy models and two advection approaches. The Intra-Americas Seas Nowcast/Forecast System (IASNFS), the Hybrid Coordinate Ocean Model (HYCOM), and the Northern Gulf of Mexico Nowcast/Forecast System (NGOMNFS) provide current direction and magnitude at hourly time-steps, at 6km, 4km, and 2km resolution, respectively. We apply the current vectors from these models to 1km resolution SeaWiFS-derived bio-optical properties (chlorophyll, backscattering coefficient, total and inorganic suspended particulate matter concentration) to produce advected, surface forecast images, using both a passive tracer advection scheme (Eulerian approach) and a particle trajectory/accumulation scheme (Lagrangian approach). Difference images between the next-day, satellite-derived optical fields and the model-advected fields provide a quantitative assessment of the forecast accuracy of the three models and two advection schemes, to assess the degree to which physical dynamics control the bio-optical distribution patterns. We compare different seasons (spring vs. fall) as well as different forecast periods (24 vs. 48hr). In addition to the model/imagery comparisons, we perform model/model comparisons and comparisons between the two advection approaches, for examples in the northern Gulf of Mexico.

INTRODUCTION

Remote sensing of ocean color provides synoptic surface ocean bio-optical properties but is limited to real-time or climatological applications. Many applications, including navy mission planning using electro-optical sensor performance models, would benefit from a forecast capability. Although fairly reliable operational forecasts have been established for years for weather (winds, rain, fronts, tropical

storms) and physical oceanographic properties (currents, temperature, salinity, sea-surface height), development of forecast systems for bio-optical and biogeochemical oceanographic properties (chlorophyll, backscattering coefficient, suspended particulate matter concentration) is in its infancy. The tools, such as reliable, accurate satellite ocean color imagery, a better understanding of coupled ecological and physical processes, and the ability to couple imagery and models, now exist to address this deficiency.

The forecasting of bio-optical properties can be approached with differing levels of complexity. The first level is to simply treat the optical properties as pseudo-conservative passive tracers and advect them forward in time using current fields derived from numerical circulation models. This approach only accounts for dynamical processes (winds, currents, tides) and does not include biogeochemical mechanistic processes (growth, grazing, sinking, resuspension). Higher levels of complexity involve coupling in situ measurements (ship, gliders, moorings) and complex ecological and light models with the satellite imagery and circulation models. However, with the more complex approaches, a number of questions arise. How well do we understand the system? Can we obtain reasonable estimates of the required state variables? What level of complexity is required to adequately represent the system?

Although we are beginning to address these questions and make advances with satellite assimilation and coupled ecological/light/circulation models, here we present results for only the simplest approach that treats the optical propertics as passive tracers in an advection/diffusion scheme. We must first address the forecast accuracy of this more basic system before tackling the more complex approaches. Perhaps the simplest approach will adequately balance accuracy requirements, processing speed, and operational requirements, obviating the need for the more complex, computationally expensive approaches. This work begins to address the spatial and temporal limitations and errors associated with the passive tracer advection approach. We can assess where this approach does *not* adequately represent the bio-optical distributions, indicating that a more complex modeling approach may be warranted.

By assessing how closely the satellite-observed and model-predicted distributions correspond (difference between the two images), we will determine the extent to which physical forcing represented in the model controls the optical distributions. The difference will demonstrate the limitations of the passive tracer advection approach (due to the omission of the biogeochemical processes in the models). This approach provides a unique and quantitative capability for understanding coastal processes and physical bio-optical responses by using SeaWiFS bio-optical imagery as a natural tracer or "dye study".

OBJECTIVES

Our objectives are to: (1) produce optical forecasts at short-time scales (24-48 hrs) by coupling satellite imagery and circulation models; (2) compare forecasts from multiple models and advection schemes; (3) compare forecasts for multiple optical products, different seasons, and different forecast periods; and (4) compare model forecasts to actual distributions (from next-day satellite imagery) to assess forecast errors.

BACKGROUND

The Naval Research Laboratory (NRL) at the Stennis Space Center (SSC) in Mississippi has developed an Automated Processing System (APS) that ingests and processes AVHRR, SeaWiFS, MODIS,

MERIS, and OCM satellite imagery (Martinolich 2006). APS is a powerful, extendable, image-processing tool. It is a complete end-to-end system that includes sensor calibration, atmospheric correction (with near-infrared correction for coastal waters), image de-striping, and bio-optical inversion. APS incorporates the latest NASA MODIS code and enables us to produce the NASA standard SeaWiFS and MODIS products, as well as Navy-specific products using NRL algorithms. We can readily test and validate new products and easily incorporate new algorithms from other investigators. In addition, as we make modifications to the algorithms, we can easily reprocess many data files (dozens of scenes/day) and compare to previous results. Furthermore, we can automatically extract image data from regions-of-interest to facilitate time-series analyses, and from specific locations for match-ups with *in situ* ship station data. We maintain compatibility with NASA/Goddard algorithms and processing code.

NRL/SSC operates both L-Band and X-Band real-time receiving sites. We collect, process, and archive every AVHRR, SeaWiFS, and MODIS (both Terra and Aqua) pass covering the Gulf of Mexico on a daily basis. We maintain a web page and on-line image database with browse capabilities, covering several ocean regions; the databases are accessible at http://www7333.nrlssc.navy.mil. Imagery from SeaWiFS and MODIS covering the Gulf of Mexico is available from our archive for the life of each sensor. Here, we focus on SeaWiFS imagery and use APS to process the selected scenes to initialize circulation models and validate the optical forecasts.

NRL has developed regional and coastal (nested) operational numerical circulation models, including HYCOM, IASNFS, and NGOMNFS. We combine satellite ocean color imagery and model currents to forecast short-term optical property distributions. The three models can advect the initial satellite bio-optical fields as passive tracers using an advection/diffusion scheme. Following model spin-up, the surface satellite bio-optical properties (eg., chlorophyll and suspended particulate matter concentrations, backscattering coefficient) serve as initial tracer fields which are advected by the models to provide optical forecasts for each property. This is a Eulerian advection approach and it provides forecast surface optical fields at hourly time steps for a period of 24-48 hours. Here we compare the model forecast bio-optical fields at the surface with the surface satellite imagery. We also examine a Lagrangian particle tracking approach, as described below.

Thus, we can compare the optical forecasts from the three models and the two advection approaches to the actual distributions observed in the next-day satellite imagery. In both advection approaches, there is an implicit assumption that the bio-optical property is conservative. Although this is not strictly true, of course, it may be approximately valid over the short time scales (1-2 days) that we are examining, particularly in coastal areas where transport processes might be expected to dominate biological processes. Therefore, we consider the optical properties to be "pseudo-conservative" tracers for our purposes. The errors between the observed and predicted fields can then give some indication of the extent to which the biological distributions are controlled by dynamical processes (under the further assumption that the circulation models perfectly represent the actual advection/diffusion processes).

METHODS

Imagery
We selected two periods of clear imagery (14-15 April 2004 and 7-9 November 2007) covering the northern Gulf of Mexico coast from Atchafalaya Bay, Louisiana in the west to Pensacola Bay, Florida in the east. SeaWiFS ocean color imagery for these periods was processed through the NRL APS to

produce chlorophyll concentration, backscattering coefficient at 555 nm (b_b555), total suspended sediment concentration (TSS), and suspended inorganic particulate (PIM) concentration. Chlorophyll was estimated using the oc4v4 algorithm (O'Reilly et al., 2000) for the April time period and the Stumpf algorithm (Stumpf et al., 2000) for the November time period. The backscattering coefficient was estimated using the QAA algorithm (Lee et al., 2002) and TSS and PIM were estimated following Gould (2008) and Gould et al. (2006). We compare optical forecasts for chlorophyll, b_b555, TSS, and PIM to assess whether the simple advection/diffusion scheme employed here works better (i.e., has lower errors) for one of these properties relative to the others. For example, if chlorophyll concentration and distribution is impacted by growth and grazing, processes not accounted for in this approach, to a greater extent than b_b555 or TSS, we might expect larger errors between the actual and predicted chlorophyll distributions than for the other two optical properties.

Circulation Models

A real-time ocean nowcast/forecast system (ONFS) has been developed at the Naval Research Laboratory (NRL) (Ko et al, 2008). The NRL ONFS is intended for producing a short-term forecast of ocean current, temperature, salinity, and sea level variation including tides. It is based on the NCOM (Navy Coastal Ocean Model) hydrodynamic model, but has additional components such as data assimilation and improved forcing. Recently, the NRL ONFS was implemented for the Intra-Americas Sea (IASNFS) that includes the Gulf of Mexico (Ko et al., 2003). A high-resolution northern Gulf of Mexico nowcast/forecast system (NGOMNFS) is nested in the 6 km resolution IASNFS to better predict the coastal circulation. The NGOMNFS has a 2 km horizontal resolution and 40 vertical layers. It is driven by the surface fluxes, wind, heat and sea level air pressure, from the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS, Hodur 1997), a high-resolution regional weather forecast model and tides (Egbert and Erofeeva, 2002). MODIS sea surface temperature and altimeter sea surface height (Jacobs et al., 2002) are used for data assimilation. NGOMNFS also includes 116 rivers and fresh water runoff points (climatological monthly mean discharge rates are used for the individual rivers). NGOMNFS sea level prediction has been compared to measurements at NOAA NOS tide gauges and shows very good agreement. Both IASNFS and NGOMNFS are operated in real-time at NRL producing predictions for the sea level, 3D ocean currents, temperature and salinity daily and were used to advect the optical fields.

The planned replacement for the dynamical model component of the Navy's operational ocean nowcast/forecast system is the hydrostatic primitive equation Hybrid Coordinate Ocean Model (HYCOM, Bleck, 2002; Chassignet et al., 2007). A 4 km, 20-layer Gulf of Mexico HYCOM that runs in real-time with high-frequency atmospheric forcing from the Navy Operational Global Atmospheric Prediction System (NOGAPS, Hogan and Rosmond, 1991) and assimilates data via the Navy Coupled Ocean Data Assimilation (NCODA, Cummings, 2005) system is the third model used in this study. Boundary conditions, including the Gulf of Mexico inflow, are from a real-time, data assimilative, 8 km, 26-layer Atlantic basin HYCOM. HYCOM is characterized by a generalized vertical coordinate which is typically configured such that the most appropriate coordinate type for a given area of the ocean is used. Thus the vertical coordinate is isopycnal in the open stratified ocean, terrain-following in shallow water and fixed-depth in the mixed layer and other unstratified regions. The transition between coordinate types occurs in a dynamically-smooth manner via the layered continuity equation. NRL also produces real-time 3D ocean nowcasts and forecasts using Global, Atlantic, Gulf of Mexico, and northern Gulf of Mexico configurations of HYCOM.

Particle Trajectory/Accumulation
Using a Lagrangian approach, we also derive optical forecasts by calculating particle trajectories. First, we extract the SeaWiFS chlorophyll values from the image corresponding to the start of the advection period into an ASCII file containing latitude, longitude and data value. The chlorophyll values are then converted to a particle concentration, using an arbitrary conversion factor. This creates the initial field that is used in the next step.

Output from the HYCOM, IASNFS, and NGOMNFS ocean circulation models includes current velocities in u (east/west) and v (north/south) directions, temperature, salinity, and sea surface height, every hour for the duration of the forecast (24 or 48 hrs). Current velocities in the w (vertical) direction computed by the circulation models were used in the Eulerian approach but were not used here in the Lagrangian approach. The ocean model velocity data is imported into Baird & Associates X-Vision2 visualization software and the Lagrangian Particle Tracking Model (LPTM) advects the initial particle field forward in time to an end date/time that corresponds to the end of the circulation model forecast. The model employs a Gaussian random-walk dispersion using temporally- and spatially-interpolated current velocities. The particle drag factor, settling velocity, and decay rate can be adjusted, but were turned off for these analyses. At the end of the forecast period, the LPTM creates an ASCII file that contains the location of every particle. A separate accumulation program then counts and bins the particles onto a SeaWiFS grid, and converts the particle count back to a chlorophyll concentration using the previous factor.

Model/Imagery and Model/Model Comparisons
For the model/imagery comparisons (eg., model forecast optics vs. next-day satellite imagery), an ASCII image dump of the satellite data was rasterized to the same geographic latitude/longitude grid as the model using ENVI software, to ensure grid alignment and equal pixel sizes. For the model/model comparisons (eg., model forecast optics from one model vs. forecast optics from another model), results from both models were rasterized to the same grid. For all comparisons, higher resolution data (imagery or model results) were interpolated to the coarser resolution data grid. Forecast errors and differences between models were calculated at each grid point using band math in ENVI:

$$[(B1 - B2)/B2] * 100, \qquad (1)$$

where B1 is the forecast value and B2 is the next-day satellite value (or the forecast value from the second model).

RESULTS

We performed multiple model/imagery and model/model comparisons to address the objectives outlined above. All forecast errors and model/model percent differences are summarized in Tables 1-3. Several images are shown more than once, however, to simplify comparisons (eg., Figs 1B, 2A, and 4A are all the same). The images cover coastal Louisiana from the Atchafalaya Bay eastward to Pensacola Bay in Florida.

(1) Seasonal: We compared 24-hr spring (14 April 2004) and fall (7 November 2007) chlorophyll, bb(555), TSS, and PIM forecasts from the HYCOM model with the Eulerian approach. In Figure 1, we only present the figures for chlorophyll. Forecast error was determined using Equation 1. For the percent error figures (1D, H), colored pixels indicate a positive error (model forecast values greater than actual values from the corresponding SeaWiFS image) whereas black/white pixels indicate
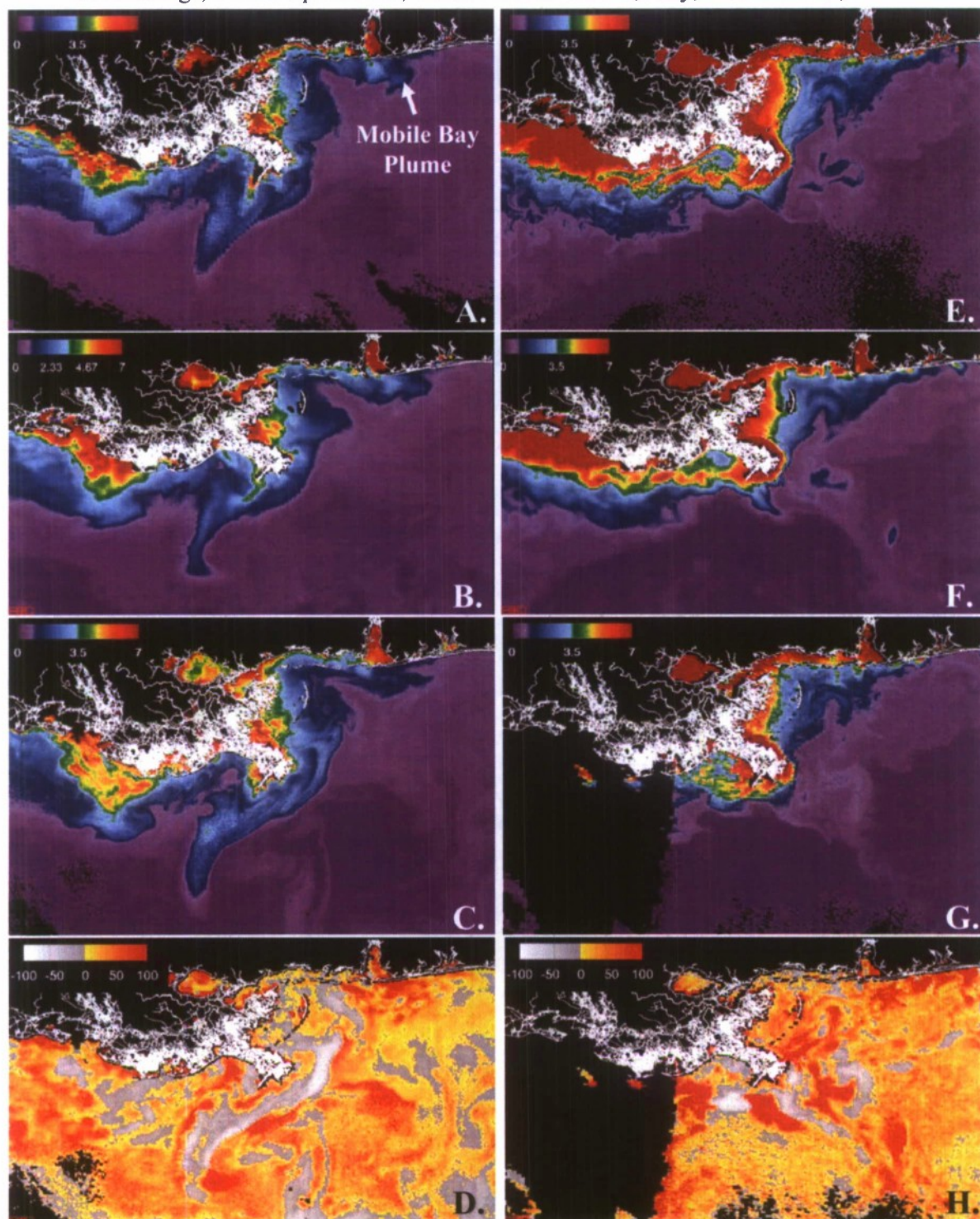
5

Figure 1. Actual and forecast chlorophyll distributions and forecast errors, HYCOM model, Eulerian approach. A-D for 14 April 2004, E-H for 7 November 2007. A. Initial SeaWiFS. B. 24-hr forecast. C. Next-day SeaWiFS. D. Forecast % error. E. Initial SeaWiFS. F. 24-hr forecast. G. Next-day SeaWiFS. H. Forecast % error.

negative errors (forecast less than actual). Black pixels are clouds or land. The model forecast in April captures the southerly extension of the Mississippi River plume and the eastward flow of the Mobile Bay plume, although there is some error in the magnitude of chlorophyll values.

(2) Optical Properties: In Figure 2, we compare chlorophyll, $b_b(555)$, TSS, and PIM 24-hr forecasts for 14 April from the HYCOM model, using the Eulerian approach (only percent error figures are shown). The distributions of the forecast errors for the four optical products are generally similar, but the magnitudes differ somewhat, with PIM showing higher errors near the Atchafalaya Bay plume, but lower errors offshore.
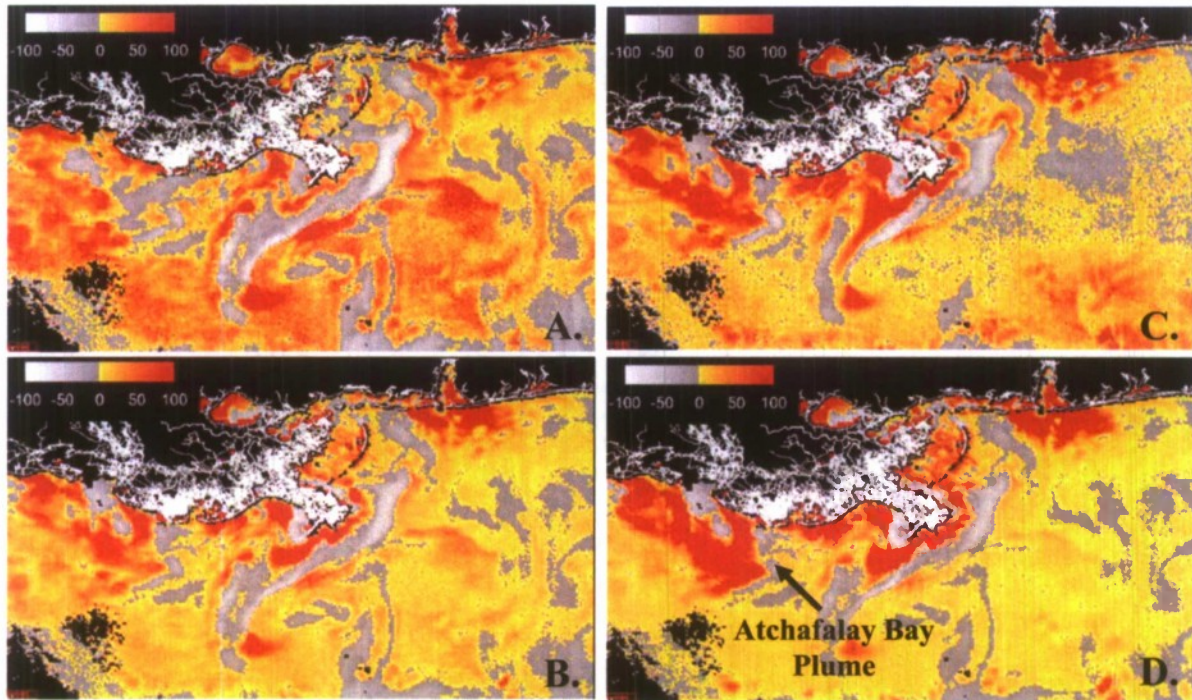

Figure 2. Optical forecast errors, HYCOM model, Eulerian approach, 14 April 2004. A. Chlorophyll. B. TSS. C. $b_b(555)$. D. PIM.

(3) Length of Forecast: Figure 3 compares the 24 and 48 hr forecasts for each of the four optical properties, for 7 November 2007 from the HYCOM model, using the Eulerian approach.

(4) Different Circulation Models, Eulerian Approach: In Figure 4, we compare the 24 hr forecasts from the three models for chlorophyll for 14 April 2004, using the Eulerian approach. The model forecast distributionas and the forecast percent errors are shown.

(5) Different Circulation Models, Lagrangian Approach: Figure 5 is similar to Figure 4, but for the Lagrangian approach.

(6) Model/Model Comparisons, Eulerian Approach: Inter-model comparisons are shown in Figure 6A-C, for the 24 hr chlorophyll forecasts on 14 April 2004, using the Eulerian approach for each model. This demonstrates how similar the three forecasts are to each other, not to the actual chlorophyll distributions from ScaWiFS, as in Figures 1-5.
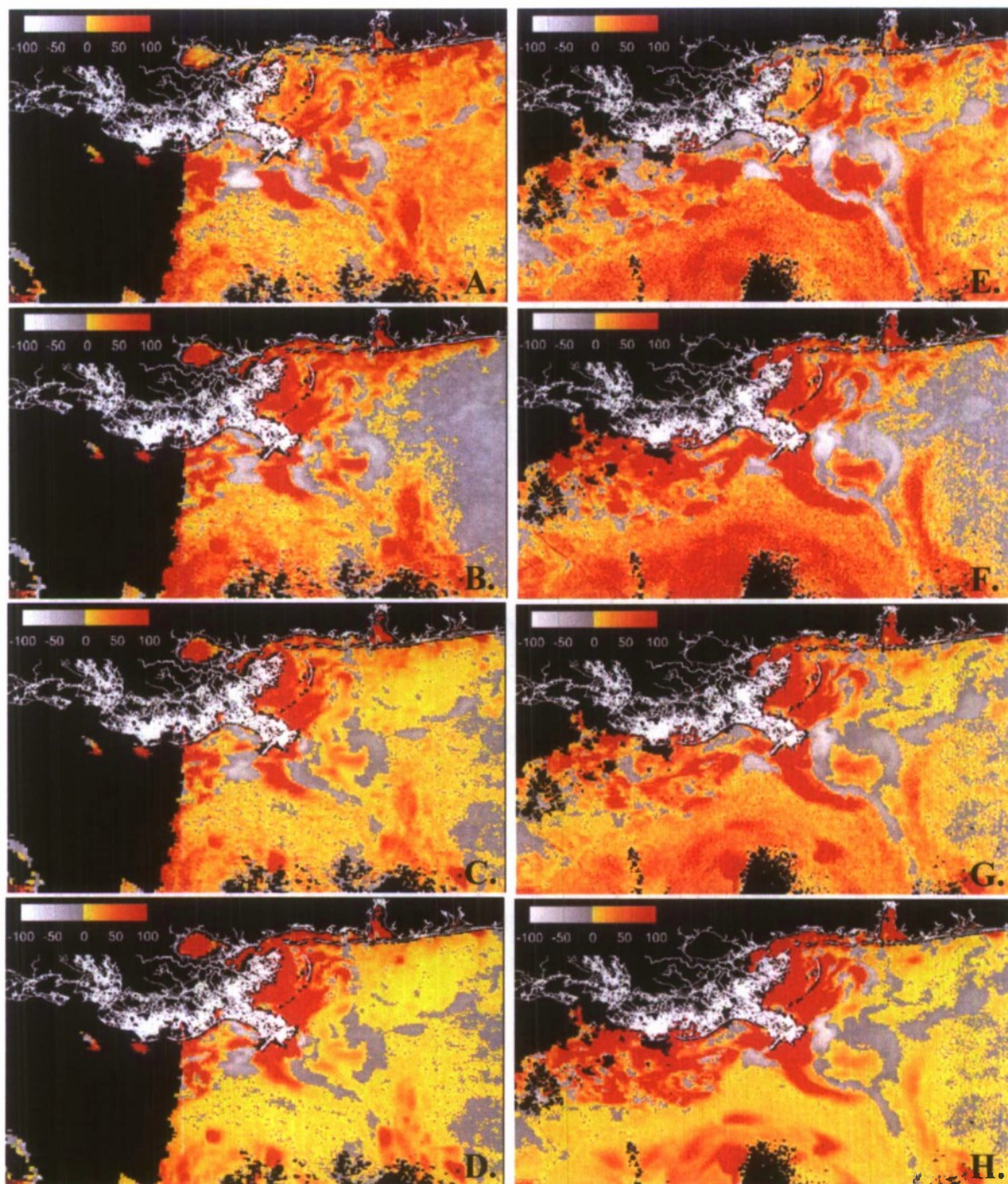
Figure 3. Optical forecast errors, HYCOM model, Eulerian approach, 7 November 2007. A-D 24 hr forecasts, E-H 48 hr forecasts. A. Chlorophyll. B. b_b(555). C. TSS. D. PIM. E. Chlorophyll. F. b_b(555). G. TSS. H. PIM.
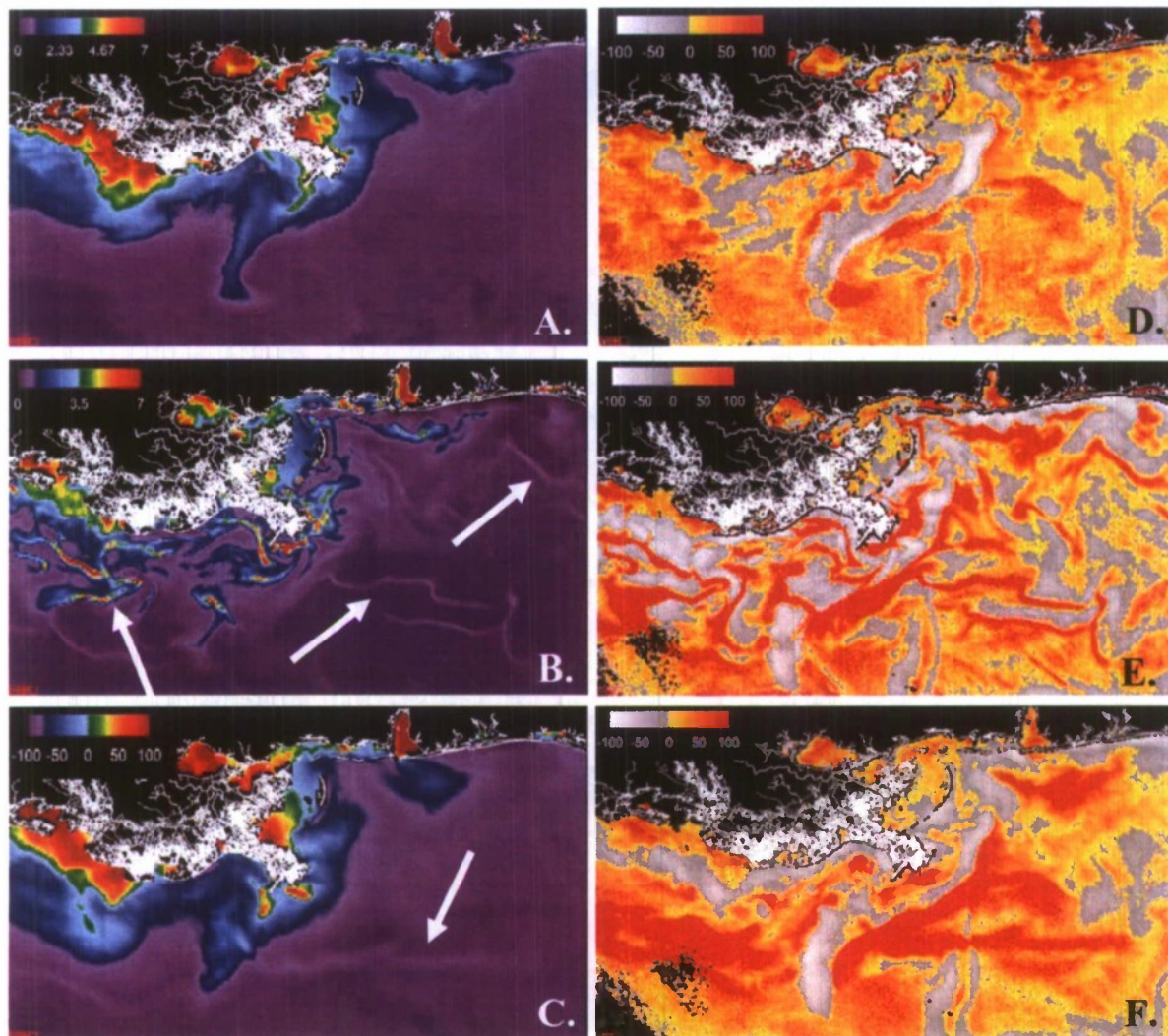
Figure 4. Forecast chlorophyll distributions and forecast errors, all three models, Eulerian approach, for 14 April 2004. A-C 24-hr forecasts, D-F forecast percent errors. White arrows indicate unusual convergence features that develop in the models, particularly the NGOMNFS and IASNFS models. These features show up as very large positive forecast errors (red pixels) in the right panels. A. HYCOM. B. NGOMNFS. C. IASNFS. D. HYCOM. E. NGOMNFS. F. IASNFS.
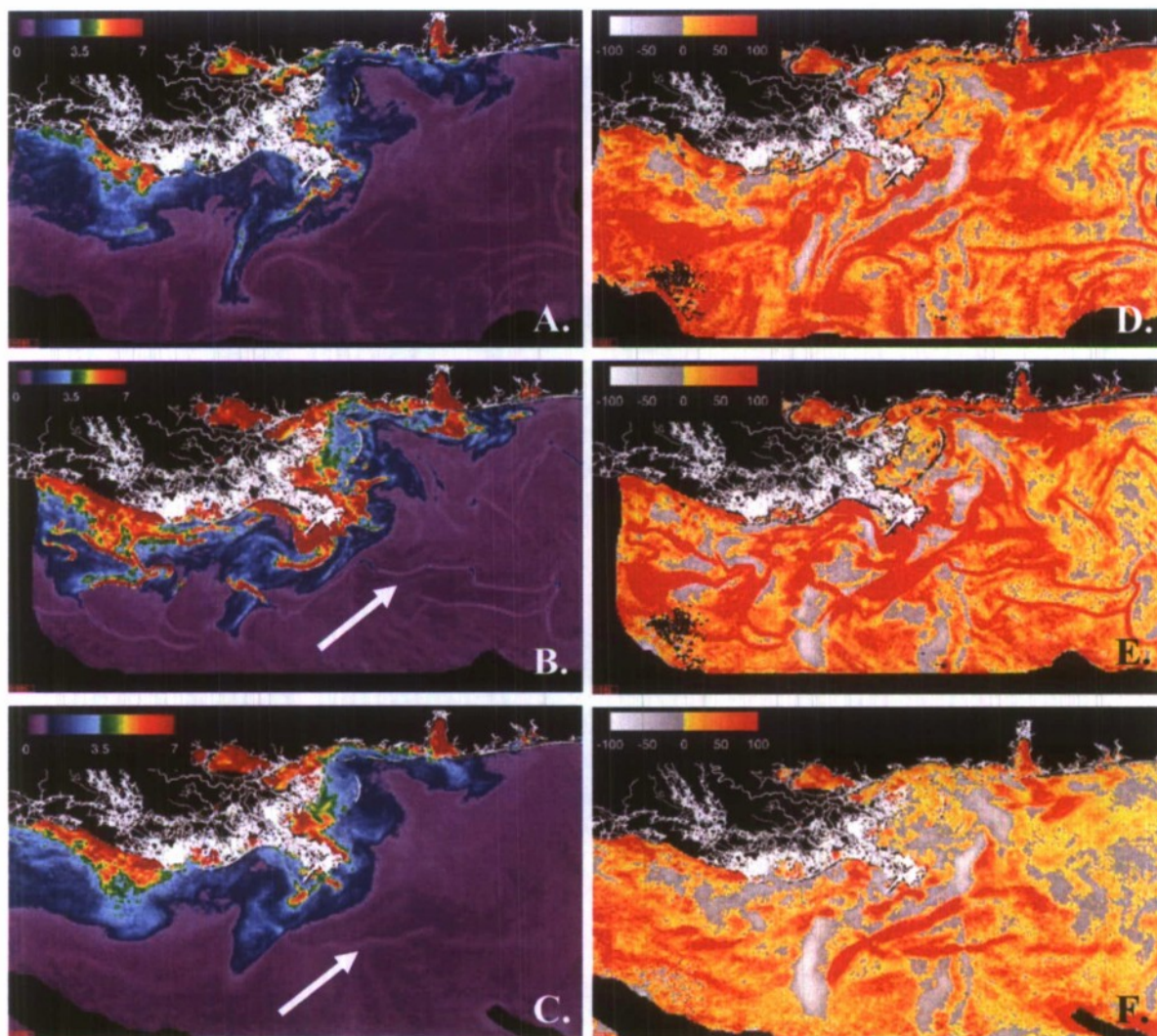
Figure 5. Forecast chlorophyll distributions and forecast errors, all three models, Lagrangian approach, for 14 April 2004. A-C 24-hr forecasts, D-F forecast percent errors. A. HYCOM. B. NGOMNFS. C. IASNFS. D. HYCOM. E. NGOMNFS. F. IASNFS.
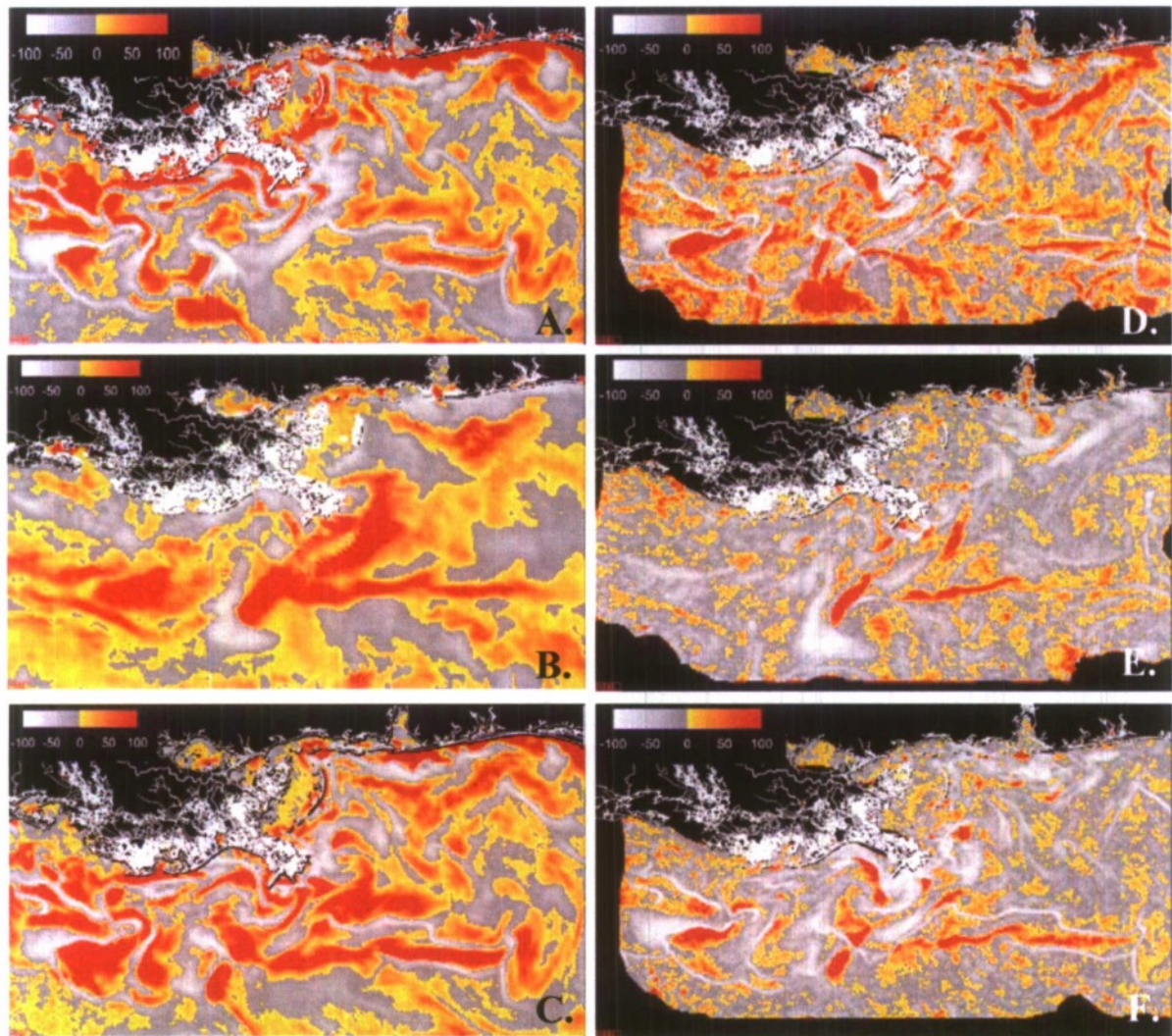
Figure 6. Model/model comparisons (percent differences) for 24 hr chlorophyll forecasts, all three models, both approaches. A-C Eulerian approach, D-F Lagrangian approach. For the percent difference calculations, the first model listed was B1 in Equation 1, the second model was B2. A. HYCOM/NGOMNFS. B. IASNFS/HYCOM. C. IASNFS/NGOMNFS. D. HYCOM/NGOMNFS. E. IASNFS/HYCOM. F. IASNFS/NGOMNFS.

(7) Model/Model Comparisons, Lagrangian Approach: Figure 6D-F shows the inter-model comparisons for the 24 hr chlorophyll forecasts on 14 April 2004, but using the Lagarangian approach for each model.

The forecast errors displayed visually in Figures 1, 2, and 3 are averaged over the entire scene and summarized in Table1, and those for Figures 4 and 5 are provided in Table 2. The model percent differences displayed in Figure 6 are averaged and presented in Table 3.

Table 1 summarizes the mean optical forecast errors for the HYCOM model using the Eulerian advection approach. These are average errors over the entire image area, for four optical properties.

Also shown are the minimum, maximum and standard deviation of the forecast errors. Two seasons are compared, spring (14 April 2004) and fall (7 November 2007). Two forecast periods are compared for 7 November (24 and 48 hr). Note that the Stumpf chlorophyll product was used in April while the oc4V4 chlorophyll product was used in November. Somewhat lower errors were observed in April than in November for the 24 hr forecasts, for all optical products except PIM which was about the same for both periods. In addition, mean 24-hr forecast errors were lower than the 48-hr forecast errors, for all optical properties, by 8-19%, indicating a decrease in model skill over time. Also note that all the forecasts show extremely high maximum errors compared to the minimum errors, although these very large errors were observed at only a few pixels. Also, all the mean errors are positive, indicating that over the entire area, the models overestimate the concentrations for all four properties. TSS showed the lowest errors in all cases, compared to the other properties.

Table 1. HYCOM forecast errors for spring and fall, using Eulerian approach, by optical property.

Date	Length of Forecast	Optical Property	Forecast % error			
			min	max	mean	std.dev.
14 April 2004	24 hr	chlorophyll	-89.5	1999.2	18.8	39.1
		$b_b(555)$	-81.7	977.2	21.3	52.1
		TSS	-81.5	481.0	15.2	35.5
		PIM	-85.0	1554.2	25.2	81.2
7 November 2007	24 hr	chlorophyll	-91.6	1878.1	37.6	94.7
		$b_b(555)$	-89.5	1913.0	25.2	58.4
		TSS	-80.2	1897.1	21.8	54.5
		PIM	-85.2	1738.2	24.8	69.1
7 November 2007	48 hr	chlorophyll	-93.0	1988.4	46.2	122.3
		$b_b(555)$	-92.0	1922.9	44.2	74.2
		TSS	-87.2	1330.4	30.0	56.2
		PIM	-93.0	1283.2	39.1	93.8

Mean errors for the two approaches for each of the three models are shown in Table 2. These are average errors for chlorophyll over the entire image area, for the 24 hr forecasts from 14-15 April 2004. Although, the NGOMNFS forecast using the Eulerian approach exhibited the lowest mean error across the scene (0.1%), some unusual "convergence lines" develop over time in this model for both the Eulerian and Lagrangian approaches (see the arrows in Figures 4B and 5B), and the forecast distributions are radically different from the observed distributions in the corresponding next-day satellite imagery. For all three models, development of these sharp convergence lines appears somewhat more pronounced in the Lagrangian approach than in the Eulerian approach (compare Figs. 4 and 5). Considering mean forecast errors, standard deviations, and ability to represent the observed distributions, the HYCOM model using the Eulerian approach seems to be the best forecast tool (compare Fig. 4D to Figs. 4E, F and 5D-F); HYCOM is intermediate in spatial resolution (4 km) between IASNFS (6 km) and NGOMNFS (2 km). The IASNFS forecast with the Lagrangian approach ranks second, and is also an option (Fig 5F). Additional work is required to better understand the differences between the forecasts from the three models, including the formation of the artificial convergence lines.

Table 2. 24-hr chlorophyll forecast errors for 14 April 2004, by model and advection scheme.

Model	Eulerian Approach				Lagrangian Approach			
	min	max	mean	std.dev.	min	max	mean	std.dev.
HYCOM	-89.5	1999.2	18.8	39.1	-99.3	1765.0	60.2	84.6
IASNFS	-96.1	1350.9	36.5	70.7	-100.0	1938.8	26.1	57.8
NGOMNFS	-96.5	1710.2	0.1	67.0	-98.2	1988.7	72.2	139.8

Table 3 shows the percent differences for the model/model comparisons, for both forecast approaches. These are average differences for chlorophyll over the entire image area, for the 24 hr forecasts from 14-15 April 2004. The results from the Eulerian approach are shown in the upper right corner of the table (shaded pink) and the results for the Lagrangian approach are shown in the lower left corner of the table (shaded blue). Overall, the NGOMNFS and HYCOM models using the Eulerian approach were most similar based only on the mean percent differences, with a 10.5% average difference between these two model forecasts. The three model/model inter-comparisons using the two approaches (Fig 6) all showed quite different spatial patterns of the forecast differences.

Table 3. 24-hr model/model percent differences for chlorophyll, 14 April 2004, by advection scheme. Pink shading represents Eulerian approach, blue shading Lagrangian approach.

Model	HYCOM	IASNFS	NGOMNFS
HYCOM		14.9	10.5
IASNFS	-13.2		19.9
NGOMNFS	13.2	-12.3	

DISCUSSION AND SUMMARY

We have linked satellite ocean color imagery with current forecasts from IASNFS, NGOMNFS, and HYCOM circulation models to produce 24 hr and 48 hr bio-optical forecast maps, using Eulerian and Lagrangian approaches. We performed model/imagery, model/model, and seasonal comparisons and assessed errors. This is a first order advection/diffusion approach that does not account for any biogeochemical mechanistic processes, only dynamical processes. Nevertheless, this is an initial attempt to develop a bio-optical forecast capability at short time (daily) scales. The bio-optical forecasts can provide important mission planning information to Navy missions using electro-optical systems. In addition, the forecast particle distributions can further understanding of coastal transport processes.

Additional work is required to evaluate and adjust the particle transport and advection parameters in the models (e.g., settling, upwelling, production rates, diffusion rates) and to reduce errors. The unusual convergence lines that develop in the forecasts (more prominent in the NGOMNFS results and using the Lagrangian approach) require further investigation. Furthermore, future work will explore the coupling of higher resolution coastal models such as the Advanced Circulation Model (ADCIRC, up to 50 m resolution) with higher resolution optical properties derived from 250 m resolution MODIS imagery.

The mean error ranges (15.2 – 46.2%) indicate that although there are differences between the models and the advection approaches, the physical dynamics control the bio-optical distributions to a large degree in the northern Gulf of Mexico coastal region examined, at least over the short time scales examined. Considering mean forecast errors, standard deviations, and ability to represent the observed

distributions, the HYCOM model using the Eulerian approach seems to provide the best forecast, and the IASNFS with the Lagrangian approach ranks second. The optical forecasts presented here provide a new understanding of coastal processes and a direct input into defining the sources and sinks of carbon pools in the coastal ocean. This capability is provided by directly coupling circulation models and satellite ocean color imagery.

ACKNOWLEDGMENTS

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